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GB 2130620 A GB 2056518 A GB 0924868 A

(58) Field of search
UK CL (Edition K) E1D

(54) **Geodesic structure**

(57) A geodesic structure 10, for greenhouse construction for example, includes polygonal networks of principal structural flat panels, 11 and/or stressed skin shell plates, 12 which are interconnected through their slender load-bearing flanges, 13 to enclose open space working environment and to define the spherical curvature of the spacedome. The spacedome's flat panels, 11 or shell plate, 12 can be prefabricated and the structure can be erected with these panels on site, without use of any formworks starting from the perimeter of the space toward the apex of the spacedome. Thus they offer great economy through efficiency of construction and the panel fabrication techniques.

fig 1

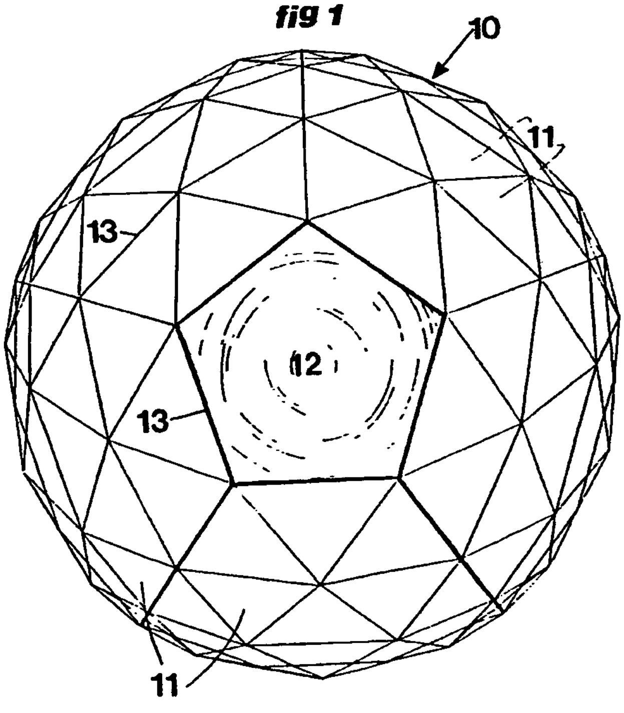

fig 2

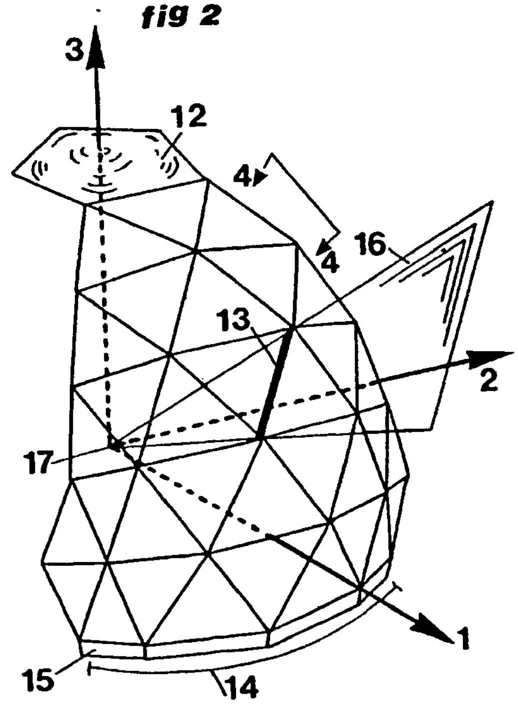

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fig 1

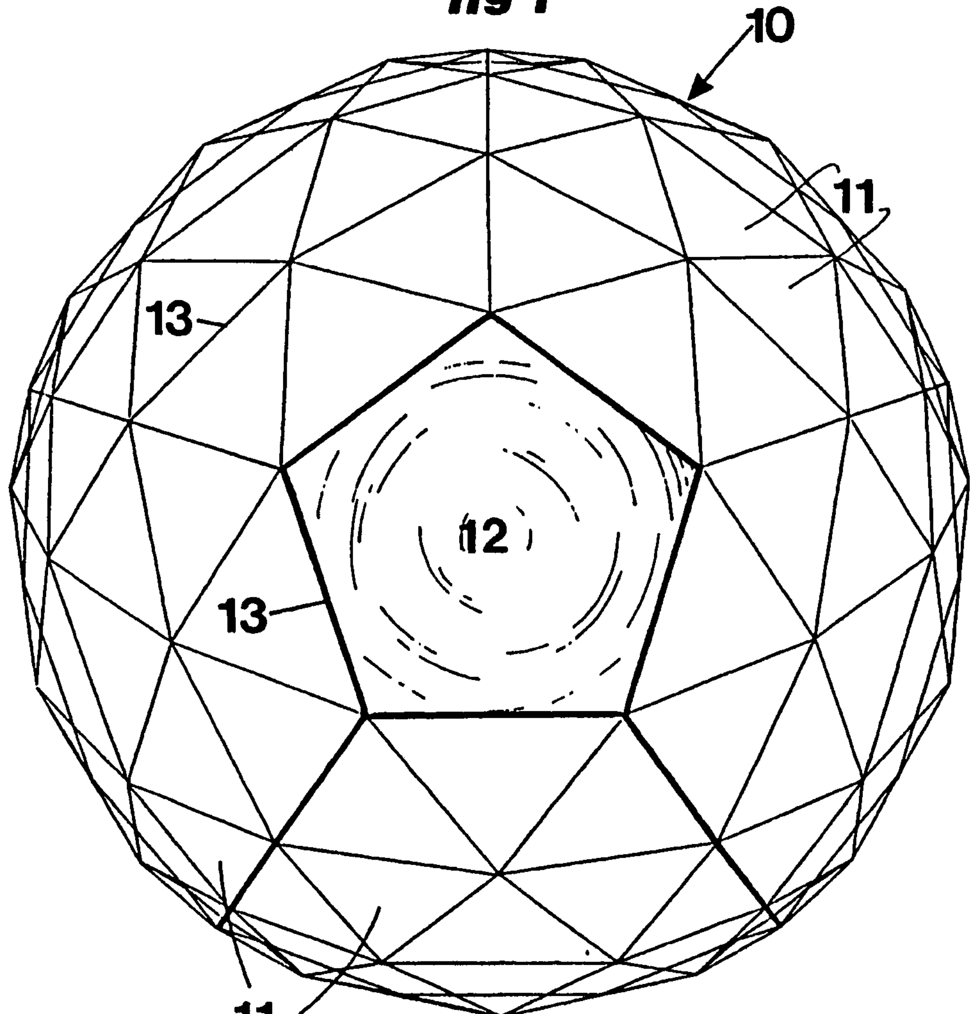
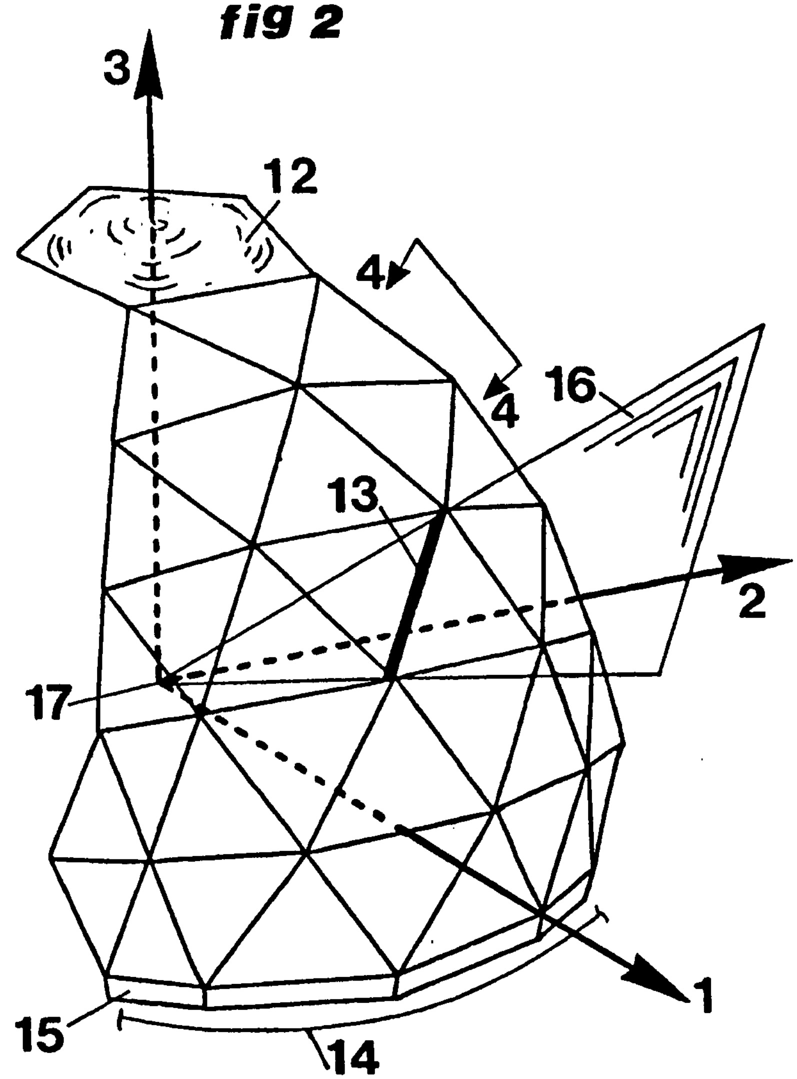


fig 2



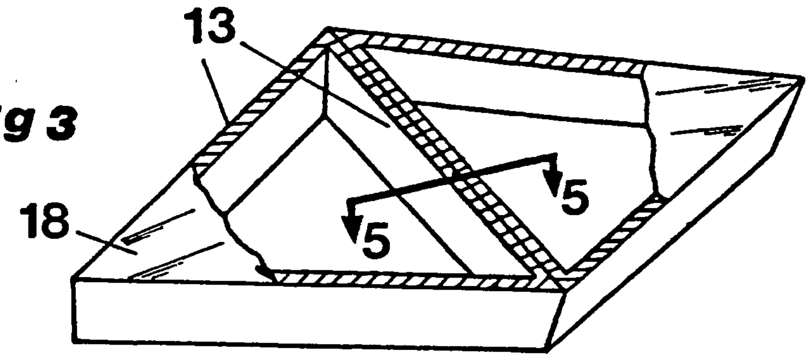


fig 3

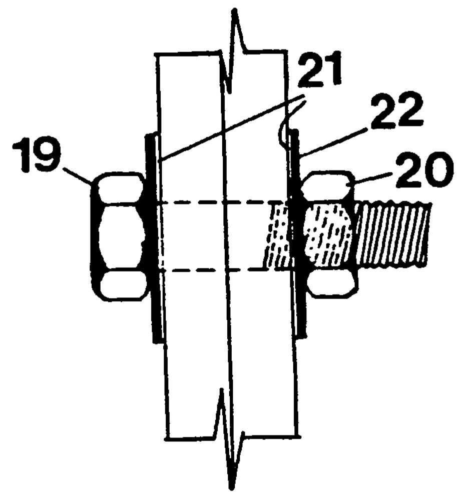


fig 4

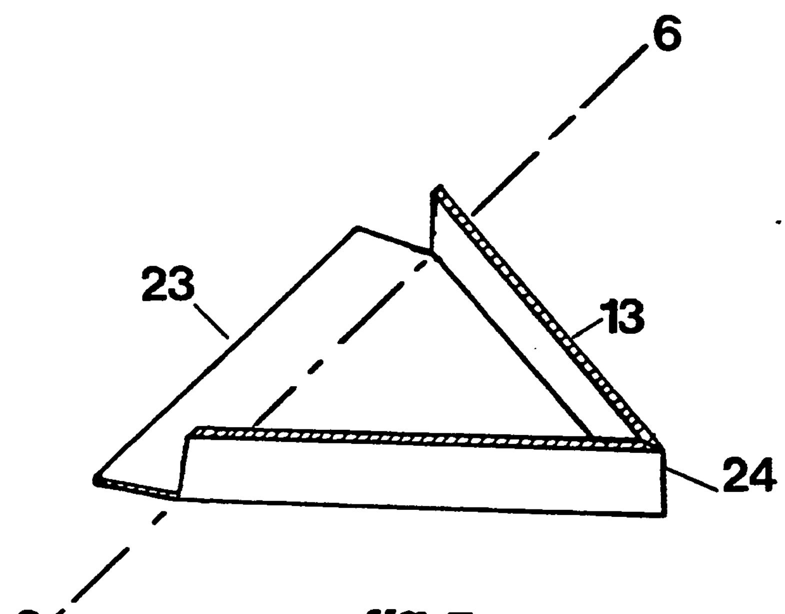


fig 5

GLAZED CURVED SURFACE SPACEFRAME STRUCTURE

This invention relates to glazed structures for enclosure of open space working areas which might include structures such as greenhouse, conservatory or solarium. More particularly, this invention relates to modular, rigid-plastic panel, shell plate or integral panel-skin arrangement. The integrated assemblage of these panels have potentials for achieving coverings for all weather open space working environments and also a good structural efficiency to resist environmental and gravity loading.

Since the popularisation of geodesic domes by R.B Fuller U.S. patent No. 2,682,235 there has been rapid growth in the scale of use and in the size of single and double-skinned curved surface space frames. Where high strength low weight materials are used, the scope for providing slender coverings of open spaces, taking advantage of many economies of scale, become most attractive. The dome continues to be used in a variety of applications of its basic geometry and construction. As a measure, assembly of structural frame members with triangulated sheets of materials has been described in U.S. patent No. 3,477,752 and for a geodesic-type dome construction in U.S. patent No. 3,909,994. This class of spacedomes consider in their construction the assemblage of structural frame member which are interconnected at joints by means of some kind of pre-fabricated, more often complex metal alloy connectors, and openings are usually covered by sheets of light weight materials which are secured around their edges to the extruded structural members and connection devices, hence the spacedomes' resistance to self-weight and applied loads are concentrated into structural members and the shell-skin or coverings do not contribute to the overall stiffness of the dome.

To resist out-of-plane and in-plane distortions, the constituent structural members in this class of spacedomes are usually doubly symmetric about their principal axes and hence have aspect ratio of unity, which make them bulky in appearance when used in glazed spaceframe structures. Also, the complexity involved in the construction of connectors; such as being made adaptable to secure and retain different thickness of sheets of materials, and more

significantly to secure and join, with a prescribed fixity, the incoming members at a common joint, have a major influence on their overall dimensions, which is aesthetically not suited when used in a single layer glazed spacedomes.

As an alternative, this invention, making use of advances in plastic technology, together with the physical understanding of the process leading to the buckling of reticulated shells, has developed a simple, cost-effective and efficient method of roofing open spaces when glazing has the dominant role.

It is well understood that under the high levels of axial force developed in the constituent members of a reticulated shell there is the possibility of local member, or groups of members, suffering a buckling failure. Resistance to this essentially local buckling is provided by the bending stiffness of the individual members. The member cross-sections in this invention are so chosen to have a high bending stiffness against out-of-plane distortions, this results in slender flange members that are not bulky in appearance, and the lateral or in-plane bending distortions are constrained by an integral panel-skin arrangement. When plastic materials with acceptable physical and optical properties are selected for their fabrications would result in crystaline clear modular units, which upon integral assemblage forms any prescribed curved surface in which the structural flange members have become integrated part of the glazing system.

Automotive fabrication of these modular units, by means of injection or compression mouldings, or thermoforming might require, for the reason of economy or ease of fabrication, that a single plastic compound with a uniform thickness of material be used. This process of fabrication would result in enhancement of the out-of-plane bending resistance of the constituent members, since they now enjoy the possession of the cross-sectional area's property of a 'T' section.

The modular polygonal units described hereinbefore are usually in the form of flat triangulated panels. However, there is also the possibility that each unit could have more

than three sides. Polygonal units having more than three sides, in particular units such as pentagon, hexagon or the like require a greater cross-sectional area in their flange members. This is the consequence of the fact that in a curved surface composed of these pentagonal/hexagonal units, there are only three members that are met at each internal nodal joint. In this circumstance, it is more desirable and economical to adopt a stressed-skin system rather than the panel-skin arrangement. Although a glazed curved system could also exist to adopt both systems in conjunction in its erection. Perhaps one of the earliest form of the stressed-skin system is the one described by the U.S Pat. No. 3,058,550, for a geodesic dome system. This system is made-up of a plurality of diamond-shaped tetrahedral sheet metal units which carries and transmits its own weight and applied loads through their skin members and associated struts to perimeter foundations. This invention although is distinctly different from its approach, adopts the same conceptional ideas of transmitting applied loads and gravity loading to the perimeter abutment at supports that are fixed. Such a stressed-skin system in this invention is achieved by plurality of polygonal rigid plastic shell-plates each having more than three sides and curvature equal to that of the principal curvature. That is in the case of spherical spacedome, each of the modular shell-plate unit have a radious of curvature equal to the radious of curvature of the spacedome itself. There again, selecting plastic materials with acceptable physical and optical properties in their construction results in a pure glazed spaceframe, enhancing its majestic architectural appearance.

Other objects, features and advantages of the invention will now be described by way of a specific example made to spherical spacedome possibly for the construction of a greenhouse and with reference to the accompanying drawings in which:-

Figure 1 is a plan view of a spherical spacedome according to this invention;

Figure 2 is a fragmentary perspective view of the spacedome taken from the solid heavier line in Figure 1, with reference plane being shown to indicate the orientation of one typical flange member;

Figure 3 is a perspective view of the two adjacent triangulated panels taken along line 4-4 in Figure 2 to explore the panel-skin arrangement;

Figure 4 is a fragmentary plan view taken along line 5-5 in Figure 3, illustrating the connection detail for securing the unit to similar units;

Figure 5 is a perspective view of the uniformed thickness panel unit illustrating how the marginal edges are bent to constituent a whole complete unit.

Detailed description

The drawing illustrates preferred embodiments of the invention in accordance with which a modular system is provided for erecting a spherical spacedome with special provision being made for prefabricating the panels.

The illustration of Figure 1 depicts the plan view of the spherical spacedome, 10 where an allotment of this figure indicated with the solid heavier line is shown in a simplified perspective view in Figure 2.

Figure 1 shows a plurality of structural flat panels, 11 and also a shell-plate, 12 located at the apex of the spacedome. The pentagonal shell-plate is secured and bolted at its perimeter flange members, 13 to the neighbouring flat triangulated panels, 11. The flat triangulated panels, 11 are also secured and interconnected through their slender load-bearing flanges, 13 to form the principal curvature of the spacedome. The principal curvature in this example, Figure 1 is spherical, but according to this invention is not the only possible geometrical form. Other upward convex geometries, such as elliptical or any other curved surfaces or barrel vaults, cylindrical panels or the like imposed by the many factors such as the dome's perimeter out-line, its size, environmental conditions and the like are possible.

The schematic perspective view of Figure 2, elucidates the spacedome's perimeter arrangement, 14 which could not clearly be defined in Figure 1. The dome's perimeter, 14 is generally composed of rhombus panels, 15 which are interconnected together and to the rest of the dome and that are fixed to the foundation by means of hold-down bolts.

Figure 2 also depicts the orientation of one typical sharing flange member, 13 of two adjacent triangulated panels with respect to the cartesian coordinate system 1,2,3. In the case of spherical spacedome, the flange member, 13 in Figure 2 is such oriented that its plane, 16 passes through the origin of the sphere, 17. In general flange members for any other curved surfaces are slightly inclined so that the flange members of adjacent panels make full face contact.

As an illustrative example, Figure 3 depicts a fragmentary isoparametric view taken along line 4-4 in Figure 2, where each of the half thickness flanges from each separate panel in Figure 3 are shown to have a full face contact. Flange members of the typical panels shown in Figure 3, can be fabricated using rigid-plastic materials, either by the process of injection or compression mouldings, using one of the many available resins such as polycarbonate, polyester, acrylic and the like, or by the process of casting from a pattern using filled or unfilled epoxy resins. A sheathing, or skin, 18 suspended from this framework, Figure 3 is for the provision of an effective lateral restraint to the deep slender members used in the flanges of panels, 13. Using a skin with adequate in-plane tensile strength and stiffness, would stabilise the tendency for lateral column buckling. The skin is usually made of thin plastic-film with high tensile strength and an adequate optical property. Occasionally, it is also required for shading purpose for example that skin fabric with no light transmission to be used.

The spacedome in this example, Figures 1,2 aloof the shell-plate at the apex, 12 is made-up of these individual panels interconnected together along their slender deep flanges. Figure 4, depicts a fragmentary plan section view taken along line 5-5 in Figure 3. Figure 4, illustrates the connection detail for holding the two half thickness flanges of the adjacent

panels. The connectors used in holding panels together are standard aluminium or nylon structural hexagonal head bolts, 19 and nuts, 20. Use of nylon, 21 and aluminium, 22 washers of a diameter of at least three times the shank diameter help to spread the load and should be used under a nut and bolt head. To prevent the possibility of occurrence of any local flange buckling between adjacent bolts, maximum permitted bolt spacing along the length of the flanges should be evaluated in advance. Due to the inability of the skin to resist any developed compressive force, the local inter-bolt buckling in the case of panel-skin arrangement, is unrestrained at the skin connection, while in the case of uniformed thickness panel is restrained.

Unlike the panel-skin arrangement of Figure 3, where two types of different materials; plastics or plastic-fabric are used in its construction, the uniformed thickness panel of Figure 5 is fabricated from one plastic compound with a uniform thickness of material. The fabrication of uniformed thickness rigid-plastic panel in this invention is achieved in one of the two following methods. The first method makes use of the resin injection or press moulding process in its fabrication. The injection moulding is the most widely used method of mass producing to close tolerance three dimensional forms over a wide range of sizes and variety of shapes. The simplest tool is a robust construction consisting of two parts, one male and the other female, which contain a cavity when closed. Where re-entrant shapes and holes are required, moulds incorporating such devices as sliding cores and collapsible side cheeks become necessary. The compression moulding system requires a male and female die which are heated to between 127 to 160 degrees centigrade. Moulding material is placed between the two haves of the tool, which are then closed together by hydraulic means. A pressure of 300 to 600 kgf/cm^2 is applied and, under the action of both heat and pressure, the moulding material becomes plasticized, fills the mould to the shape of the tool cavity and becomes polymerised, or cured. The manufacturing methods outlined above facilitate the automotive mass-fabrication of these uniformed thickness modular units. Capital cost of the injection or compression moulding however can be high especially when several different triangular panel geometries are required for erecting a curved surface spaceframe.

As an alternative the second method uses a quite distinct procedure for fabricating these different polygonal facets. With reference to Figure 5, attention now is given to the manner in which a panel configuration is imparted to. The basic sheet of plastic such as acrylic, after the delineations have been impressed in the sheet, the marginal edges, 23 may be turned up to form flanges of the panel. This creasing is performed by hot line bending, where the sheet is locally heated along its line of bent, 6-6 and simply the edge is bent along this line to a desired angle without any deleterious stretching or weakening of the plastic at the line of bending or creasing. The corners, 24 where two folding marginal edges are met at a common line are then welded or bonded together to constitute a continuity between flanges. Admitting that the lower output rates and wastage of materials are the direct outcome of adopting such a technique for fabrication of polygonal facets, it has at least at the initial stage a lower machinery cost than for injection or compression moulding, per unit weight of material processed.

Claims

1. A single layer curved surface spaceframe structure of desired planform perimeteral outline adopted for enclosure of open space working environment which is supported on foundation means along said outline, the curved surface spaceframe structure comprising of rigid-plastic polygonal structural units interconnected together to define the principal curvature of the curved surface and are attached to the abutment at supports along said outline that are fixed.

2. A single layer curved surface spaceframe structure as claimed in claim 1 wherein the structural polygonal units are of uniformed thickness flat panels and are fabricated from crystaline transparent advantageous optical rigid-plastic when glazing has a dominant role.

3. A single layer curved surface spaceframe structure as claimed in claim 1 wherein the structural polygonal units are of uniformed thickness flat panels and are fabricated from opaque rigid-plastic when the effect of shade has a dominant role.

4. As an article of manufacture for use as a building panel, the more often triangular or rhombus flat panels as defined in claims 2 and 3 are used, in the case of triangular panels each of said units have three corners where the two flange members are met when using a plastic laminate for their fabrications, the flanges of panel are the marginal edges of laminate which have been bent gradually without any deleterious stretching or weakening of the plastic at the line of bending using hot line bending technique, each of said corners of a panel are bonded along its edge to give a good fixity between flanges.

5. As an article of manufacture for use as a building panel, the flat panels as defined in claims 2 and 3 can be mass fabricated using injection or press moulding process in its fabrication.

6. A single layer curved surface spaceframe according to any preceding claim wherein the curved surface is made up from the plurality of the structural polygonal units which are interconnected together through their slender load-bearing flanges by means of bolts and nuts.

7. A single layer curved surface spaceframe structure as claimed in claim 1 wherein the structural polygonal units are composed of the rigid plastic flat panel-skin arrangement.

8. As an article of manufacture for use as a building panel, the panel-skin arrangement as defined in claim 7 wherein the panel framework is fabricated from rigid plastic using the process of injection or compression moulding.

9. As an article of manufacture for use as a building panel, the panel-skin arrangement as defined in claim 7 wherein the panel framework is fabricated from filled or unfilled epoxy resins using the process of cold-setting or hot-setting casting from a pattern.

10. As an article of manufacture for use as a building panel, the panel-skin arrangement as defined to any one of claims 7-9 wherein a sheathing or skin is made of plastic-film with high tensile strength and crystaline optical property when glazing has a dominant role.

11 As an article of manufacture for use as a building panel, the panel arrangement as defined to any one of claims 7-9 wherein a sheathing or skin is made of either skin-fabric or opaque plastic-film with high tensile strength when effect of shade has a dominant role.

12. A single layer curved surface spaceframe according to any preceding claim wherein polygonal facets of uniformed thickness and panel skin arrangement can be used in conjunction for erecting a curved surface building structure.

13. A single layer curved surface spaceframe structure as claimed in claim 1 wherein the structural polygonal units are stressed skin three dimensional rigid-plastic shell-plates having a curvature equal to that of the principal curvature of the curved surface building structure.

14. As an article of manufacture for use as a building stressed skin shell-plate as defined in claim 13, have in general more than three sides and usually are in the form of pentagonal or hexagonal shell plates, formed into shape using one of the methods of thermoforming technique.

15. A single layer curved surface spaceframe structure made up of stressed skin units as claimed in claims 13 and 14 are interconnected together along their perimeter slender edges by means of bolts and nuts and are attached to abutment at supports that are fixed.

16. A single layer curved surface spaceframe structure as claimed in claims 1, 13 to 15 wherein the structural polygonal shell-plates are fabricated from crystaline transparent rigid plastic when glazing has a dominant role.

17. A single layer curved surface spaceframe structure as claimed in claims 1, 13 to 15 wherein the structural polygonal shell-plates are fabricated from opaque rigid plastic when the effect of shade has a dominant role.

18. A single layer curved surface spaceframe structure according to any preceding claim wherein uniformed thickness panel, panel skin arrangement and stressed skin shell-plate structural units can be adopted in conjunction and by their plurality to form any prescribed curved surface building structure.

19 A single layer curved surface spaceframe structure substantially as described herein with reference to the accompanying drawings.

20 A single layer curved surface spaceframe structure substantially as hereinbefore described.

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